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Shared Spectrum in 5G Markets

Wireless Innovation Forum SSPARC Workshop

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Chief Scientist

Assists Multiple Non-Conflicted Entities

In Commercial Telecommunications and Secure Computing

- ***Chief Scientist, Federated Wireless LLC , Boston, MA***
- Expert Witness for Law Firms (not contending with the US Government)
- Hackproof Technologies, Inc., Cocoa Beach, Florida (Web Machines)

In the Public Interest, Not for Profit

- Contract Systems Engineer for The MITRE Corporation, jmitola@mitre.org
- Systems Engineering Technical Assistance to the Defense Advanced Research Projects Agency (DARPA) via Rome Research Corporation (RRC)
- The Ted and Karyn Hume Center for National Security and Technology, Virginia Institute of Technology
- Georgia Tech Research Institute (GTRI)

Dr. Mitola does not assist others in competing for DARPA business

- Smart Phone Explosion Continues
- Emerging Applications
 - Video to the smart phone
 - Internet of Things (IoT), Machine to Machine (M2M)
- Laws of Physics and Engineering Realities
- Chip-set Enabled Architecture Opportunities
- Candidate Architectures
- QoS versus QoE
- Summary and Conclusions

The Market Drivers

Exabytes per Month

66% CAGR 2012-2017

Richer content, more devices and multiple devices

Richer content
—more video

Average bestseller (Gigabytes)	
.00091	Book
.0014	Homepage
.14	Soundtrack
1.8 GB	Game for Android
2.49 GB	Movie (Standard-Definition)
5.93 GB	Movie (High-Definition)

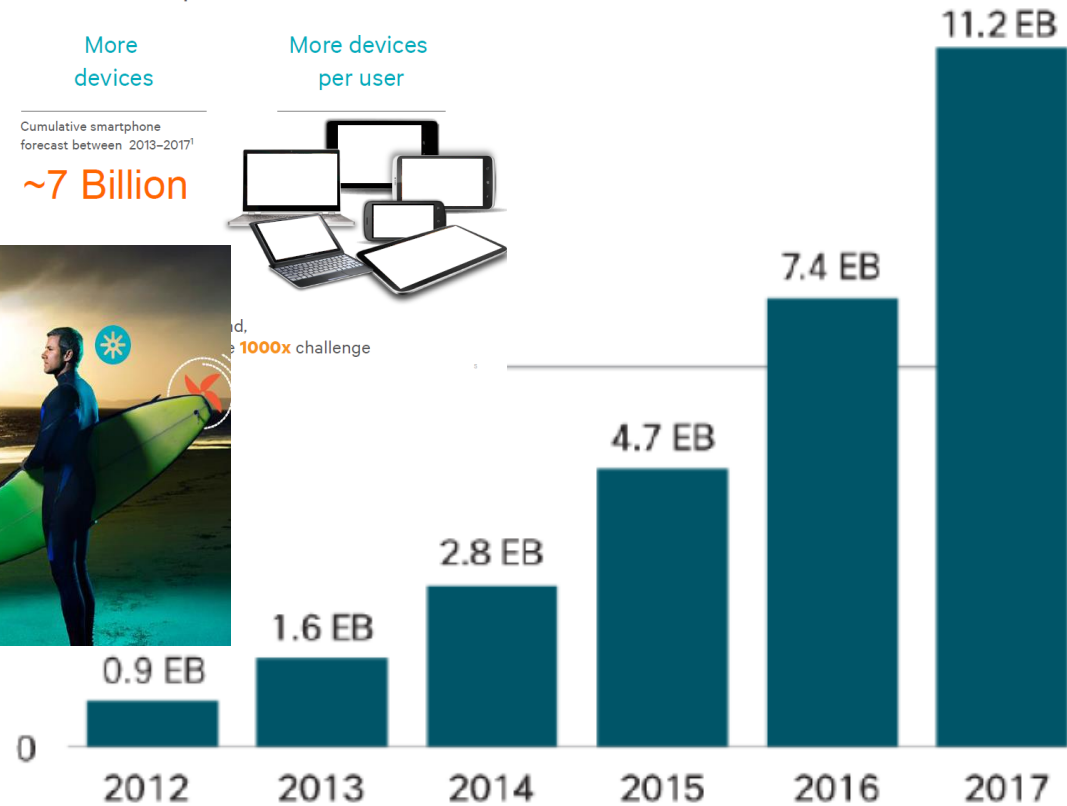
More
devices

Cumulative smartphone
forecast between 2013-2017¹
~7 Billion

More devices
per user



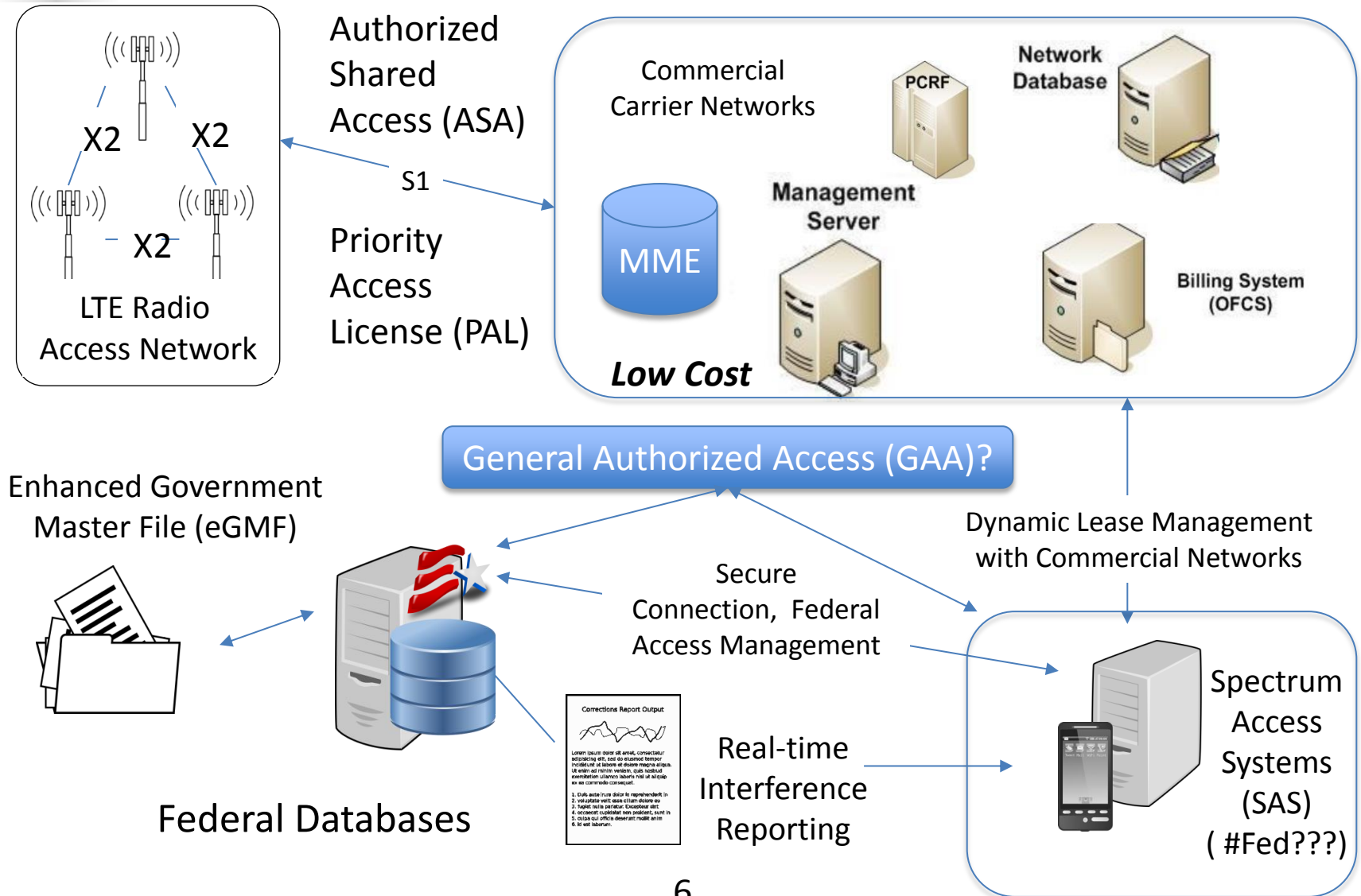
1000x challenge



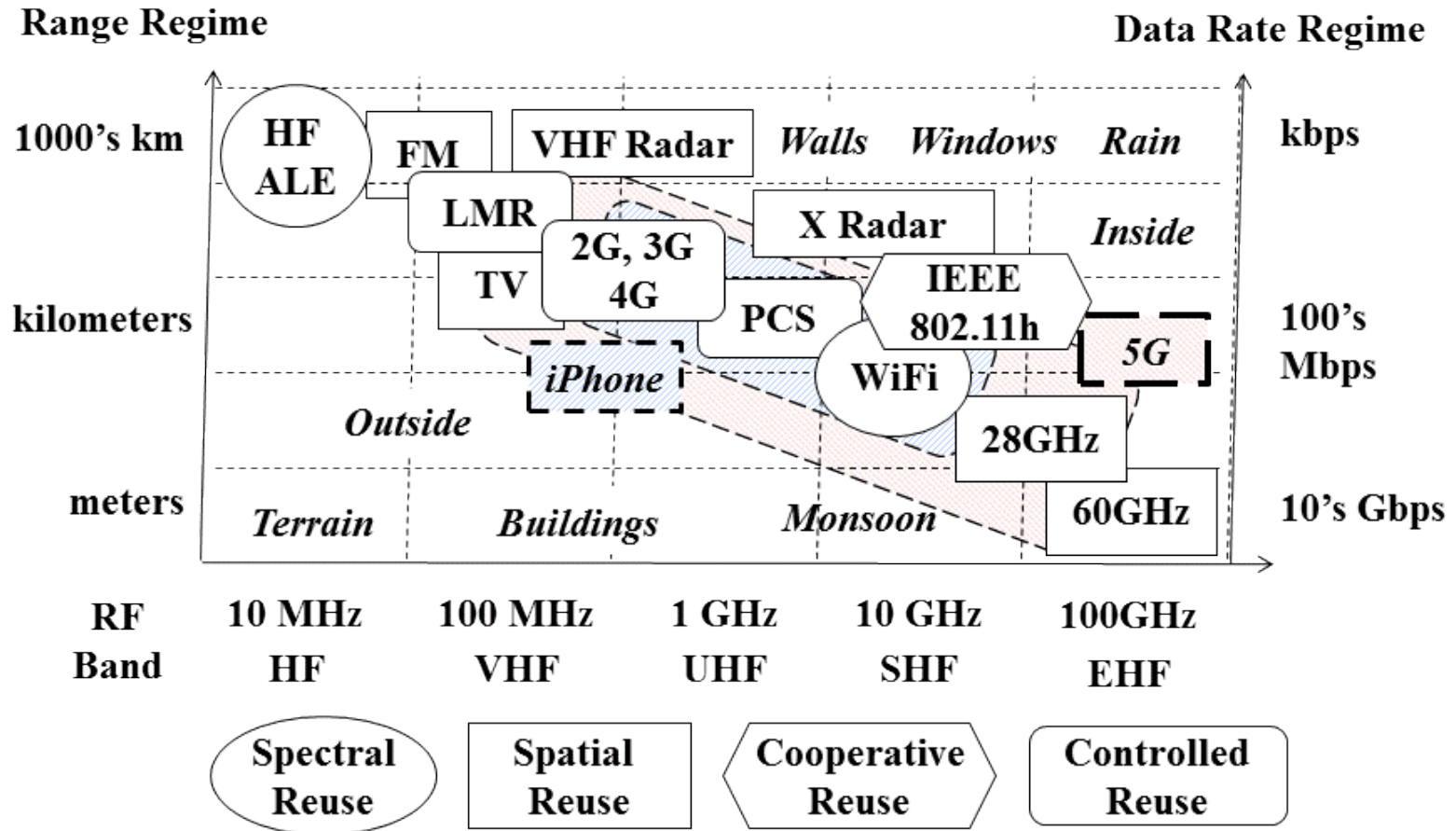
Source: Cisco VNI Mobile Forecast, 2013

- “Accelerating 5G QoE via Public-Private Spectrum Sharing” Mitola, Guerici, Reed, Yao, ... Dwyer et al
- 100 IEEE Papers on QoE in 2013
- QoE Determinants
 1. WLAN Generates QoE – consumer price points
 2. Location – privacy protection
 3. Advertising – future pushing to gigabit cache
 4. High Speed Vehicular Mobility
 5. Urban Mobility
 6. Military and Public Safety

3550 MHz Shared Spectrum



Physical Constraints





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TVWS Databases

Protected Areas ↑ **Channels** ↑ **Device Types** ↑ **Map Types** ↑

☒ TV Channels
☒ BAS Links
☒ Translators
☒ Metropolitan PLMRs/CMRS
☒ Waiver PLMRs/CMRS
☒ Offshore Radio Telephone
☒ Telescopes & Observatories
☒ Border Areas
☒ Temporary BAS Link
☒ TV translator, LPTV, Class A stations
☒ MVPD Receive Site
☒ Low Power Auxiliary

Select All Channels Unselect All Channels

<input checked="" type="checkbox"/> 2	<input checked="" type="checkbox"/> 12	<input checked="" type="checkbox"/> 22	<input checked="" type="checkbox"/> 32	<input checked="" type="checkbox"/> 42
<input checked="" type="checkbox"/> 3	<input checked="" type="checkbox"/> 13	<input checked="" type="checkbox"/> 23	<input checked="" type="checkbox"/> 33	<input checked="" type="checkbox"/> 43
<input checked="" type="checkbox"/> 4	<input checked="" type="checkbox"/> 14	<input checked="" type="checkbox"/> 24	<input checked="" type="checkbox"/> 34	<input checked="" type="checkbox"/> 44
<input checked="" type="checkbox"/> 5	<input checked="" type="checkbox"/> 15	<input checked="" type="checkbox"/> 25	<input checked="" type="checkbox"/> 35	<input checked="" type="checkbox"/> 45
<input checked="" type="checkbox"/> 6	<input checked="" type="checkbox"/> 16	<input checked="" type="checkbox"/> 26	<input checked="" type="checkbox"/> 36	<input checked="" type="checkbox"/> 46
<input checked="" type="checkbox"/> 7	<input checked="" type="checkbox"/> 17	<input checked="" type="checkbox"/> 27	<input checked="" type="checkbox"/> 37	<input checked="" type="checkbox"/> 47
<input checked="" type="checkbox"/> 8	<input checked="" type="checkbox"/> 18	<input checked="" type="checkbox"/> 28	<input checked="" type="checkbox"/> 38	<input checked="" type="checkbox"/> 48
<input checked="" type="checkbox"/> 9	<input checked="" type="checkbox"/> 19	<input checked="" type="checkbox"/> 29	<input checked="" type="checkbox"/> 39	<input checked="" type="checkbox"/> 49
<input checked="" type="checkbox"/> 10	<input checked="" type="checkbox"/> 20	<input checked="" type="checkbox"/> 30	<input checked="" type="checkbox"/> 40	<input checked="" type="checkbox"/> 50
<input checked="" type="checkbox"/> 11	<input checked="" type="checkbox"/> 21	<input checked="" type="checkbox"/> 31	<input checked="" type="checkbox"/> 41	<input checked="" type="checkbox"/> 51

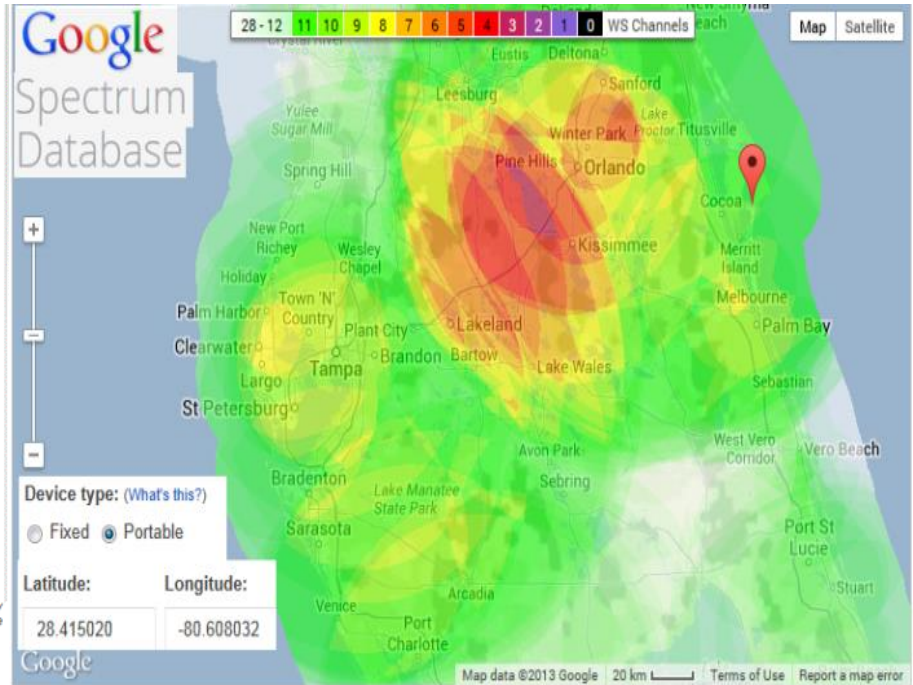
Personal/Portable 100mW(adjacent-0.4km)
Fixed <3m(adjacent-0.4km)
Fixed 3-10m(adjacent-0.7km)
Fixed 10-30m(adjacent-1.2km)
Fixed 30-50m(adjacent-1.8km)
Fixed 50-75m(adjacent-2.0km)
Fixed 75-100m(adjacent-2.1km)
Fixed 100-150m(adjacent-2.2km)
Fixed 150-200m(adjacent-2.3km)
Fixed 200-250m(adjacent-2.4km)
Personal/Portable 40mW(co-channel-4.0km)
Personal/Portable 100mW(co-channel-4.0km)
Fixed <3m(co-channel-7.3km)
Fixed 10-30m(co-channel-11.1km)
Fixed 30-50m(co-channel-14.3km)
Fixed 50-75m(co-channel-18.0km)
Fixed 75-100m(co-channel-21.1km)
Fixed 100-150m(co-channel-25.3km)
Fixed 150-200m(co-channel-28.5km)
Fixed 200-250m(co-channel-31.2km)

Road
Aerial
Hybrid

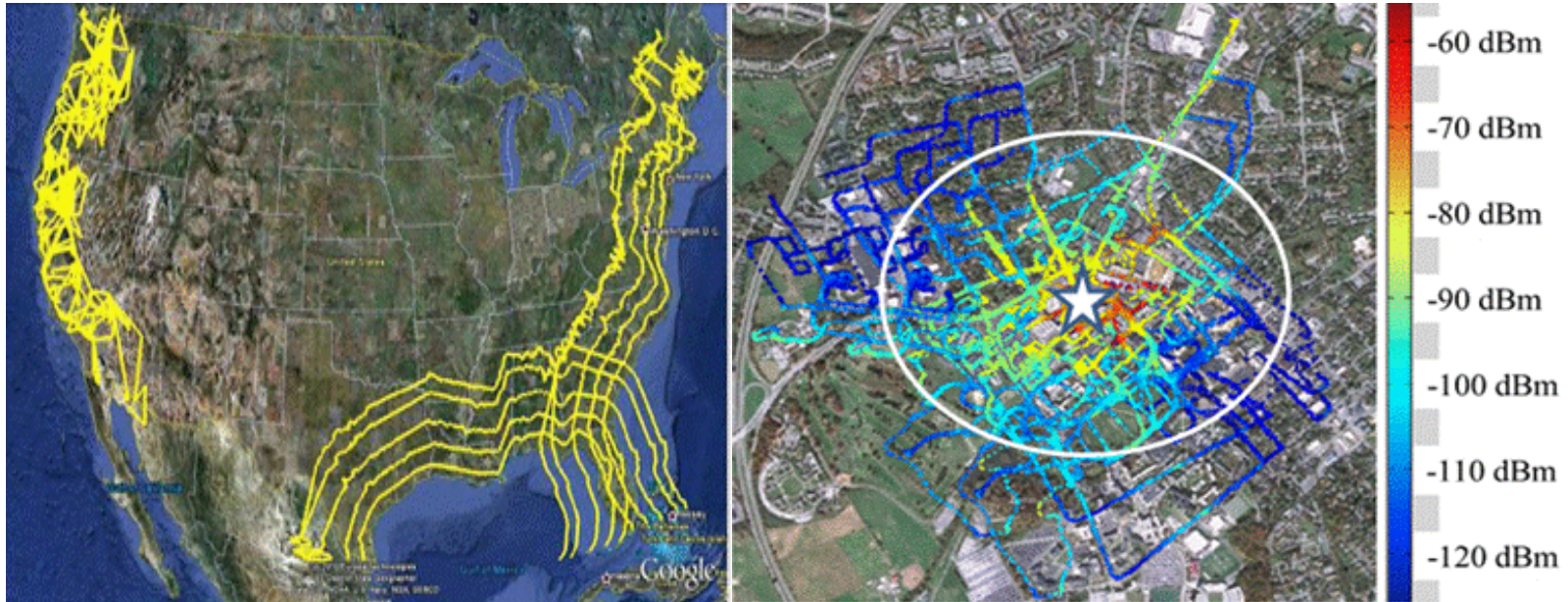
bing

This tool is intended for information purposes only and does not imply or warrant a certified TVWS service or secure interface. This tool provides information used in determining TV channels that might be available for use by TVBDs in accordance with rules defined in 47 CFR Part 15, Subpart H. The protection contours depicted do not necessarily translate directly to available channel maps, as additional factors are used in determining available white space. Additional factors used to determine available white space include, but are not limited to: device type, HAA, antenna height and adjacent channel availability. The channel authorization service provided by Spectrum Bridge ensures that interference protections afforded in 15.712 are provided. Availability of white space is subject to change over time. Current availability of specific channels does not guarantee availability in the future. Availability of channels for use by TVBDs does not guarantee interference free operation.

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✓ Spectrum availability (as of January 29, 2013)



***Federated Wireless (Allied Communications) NPRM Filing
Measure, Model, Measure, Validate is the
Foundation for Efficient Spectrum Sharing***

Spectrum Space-Time-RF

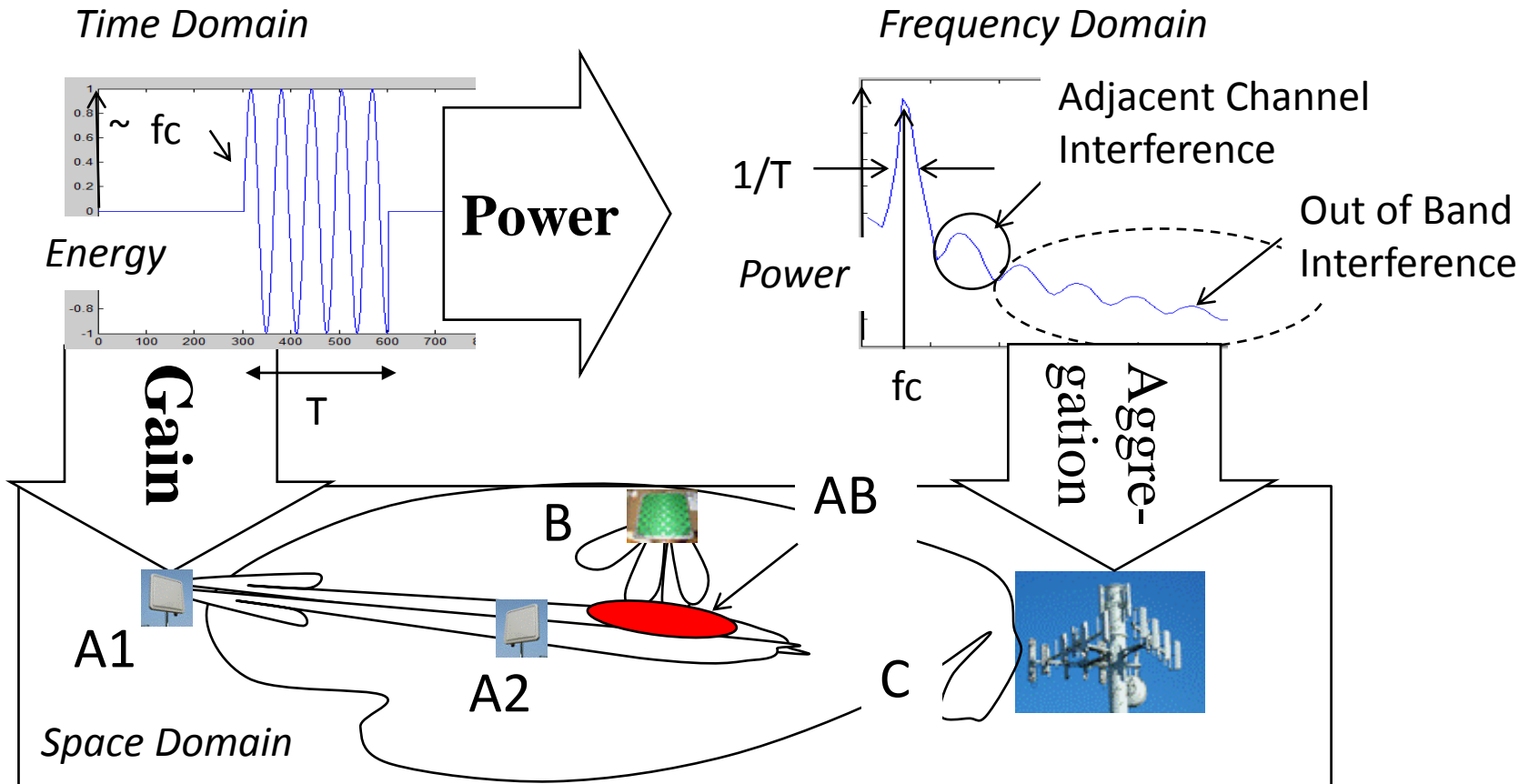


Table 1 Spectrum Reuse Ontology

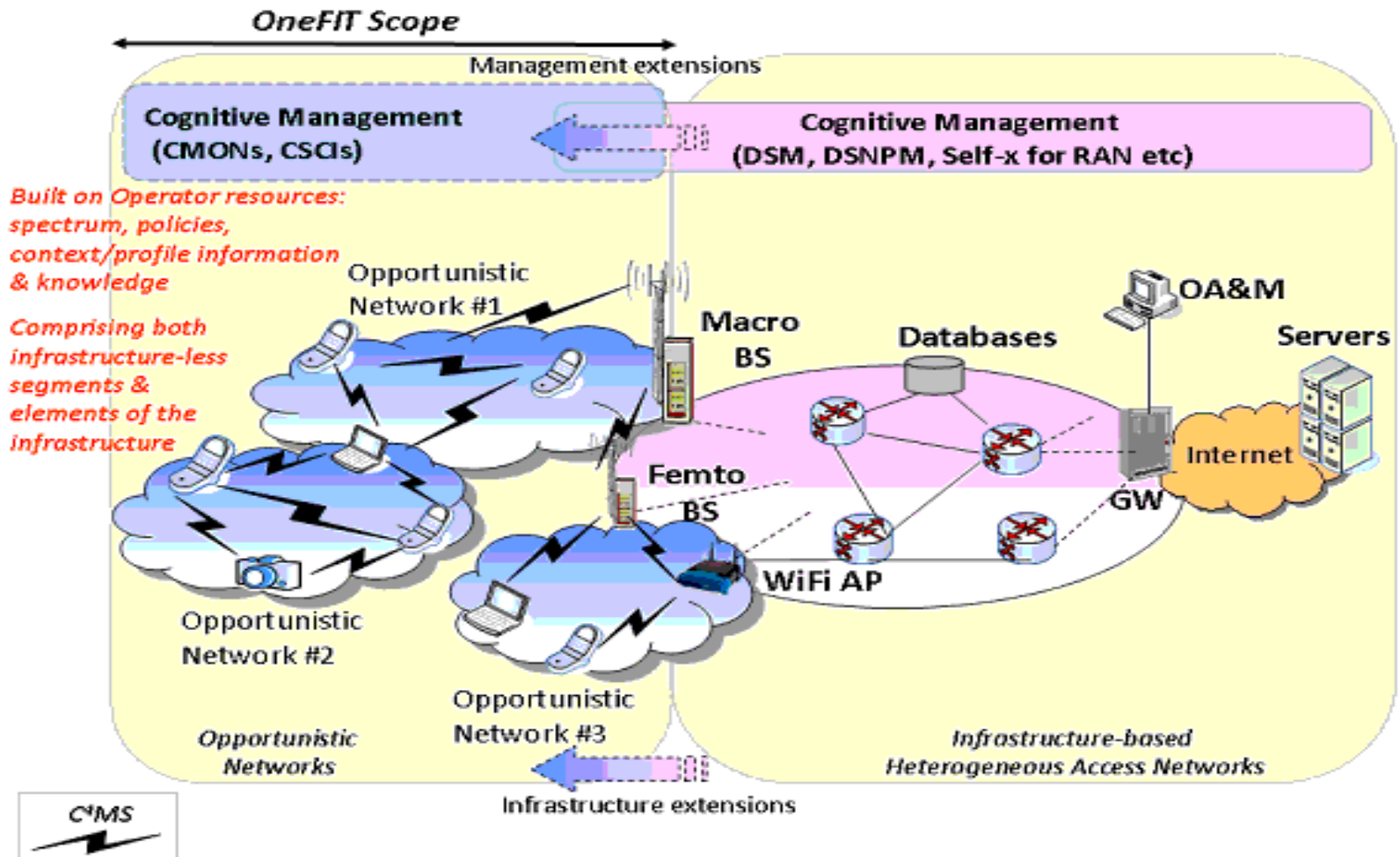
Type	Reuse Domain	Reuse Parameters	Access Protocol	Illustrative Examples
1	Frequency	Usage, power, and transmission mask	Band-specific	Regulatory band plans
1.1	Frequency	fc, bandwidth	FDMA	AMPS 1G, LMR
1.2	Frequency	Bandwidth, power	Accept interference	UWB
2.1	Space	Location, antenna radiation patterns	Location-based permission	AM, FM, TV broadcast satellite ground stations
2.2	Space	Radiated power	Channel selection	ISM Bands (WiFi), DECT
3.1	Time (fine scale)	Time slot	TDMA	GSM 2G
3.2	Time (coarse scale)	Primary user signature(s)	Etiquette	IEEE 802.11h (radar)
4	Code space	Short, long sequences	CDMA	3G
321	Space-time-frequency	Radio resource blocks (RB), power	PHY-MAC radio access protocol	LTE OFDM, OFDMA PHY-MAC



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OneFIT

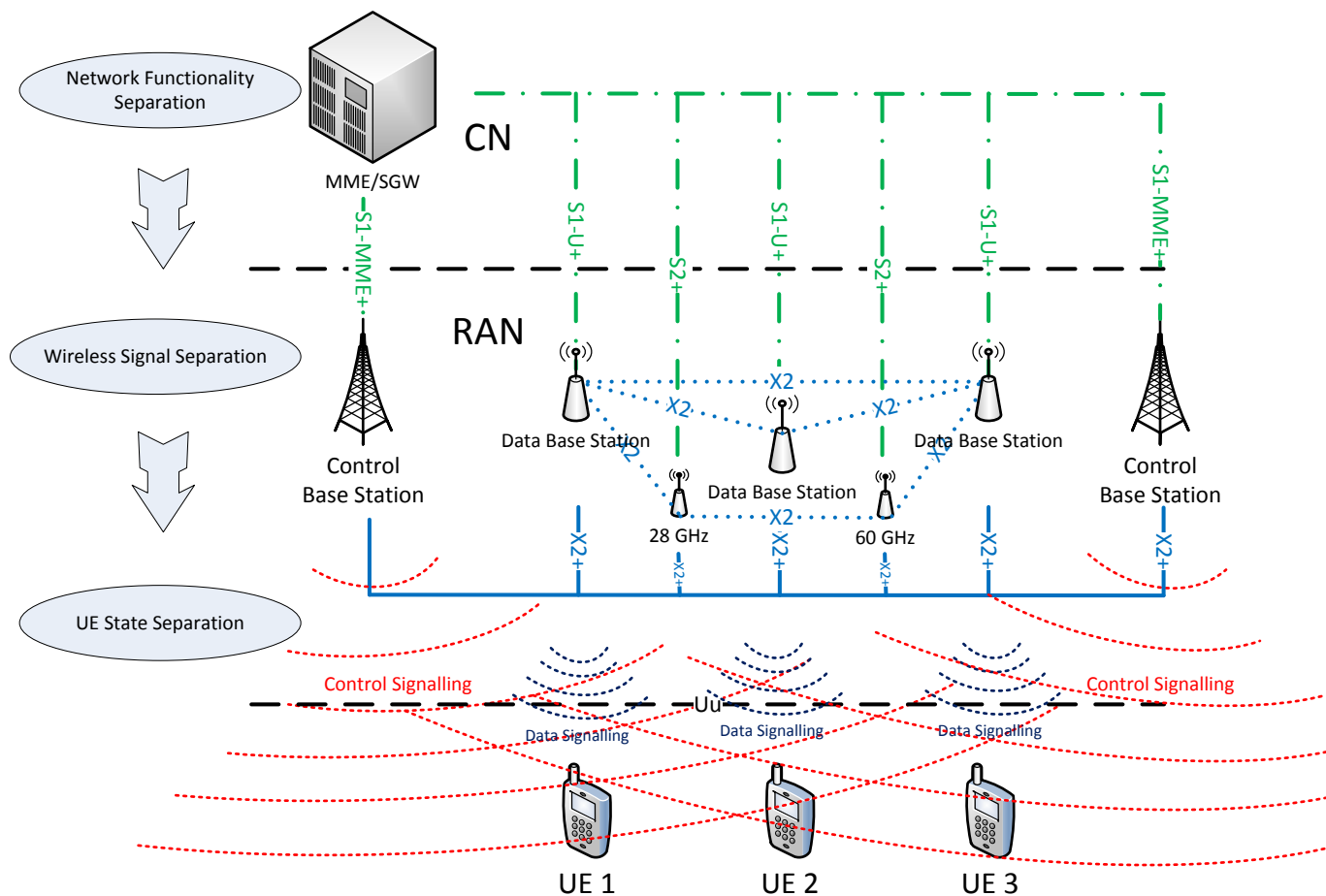




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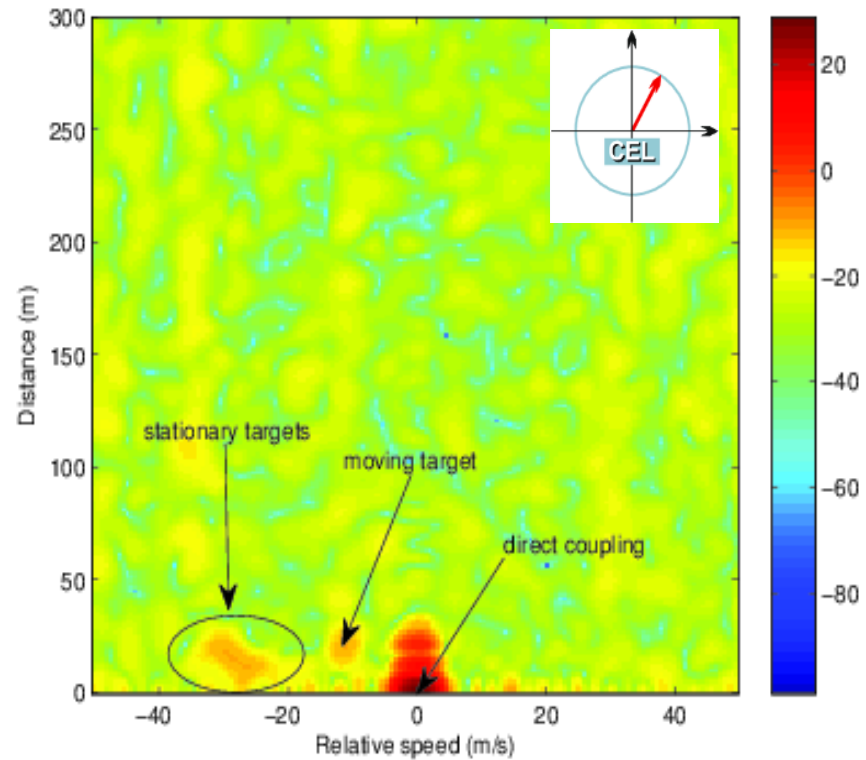
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Optimizing Spectrum Sharing



Huawei Architecture (Jul 2013) Adapted to TV White Space and 3550 SS

Multifunction RF





Multi-function Radio Frequency (RF) Devices and Networks

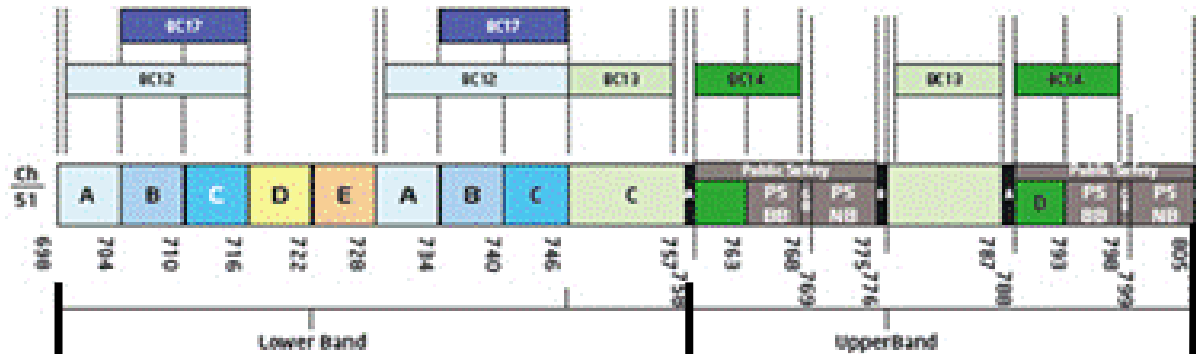


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Chip Sets

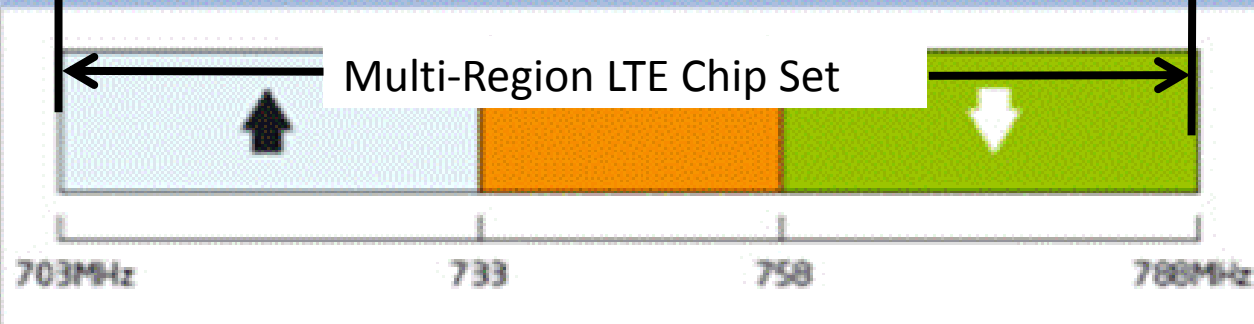
700 MHz Band Plan & 3GPP Band Classes



US LTE Chip Set

US FirstNet Chip Set

700 MHz Band Plan for Region 1



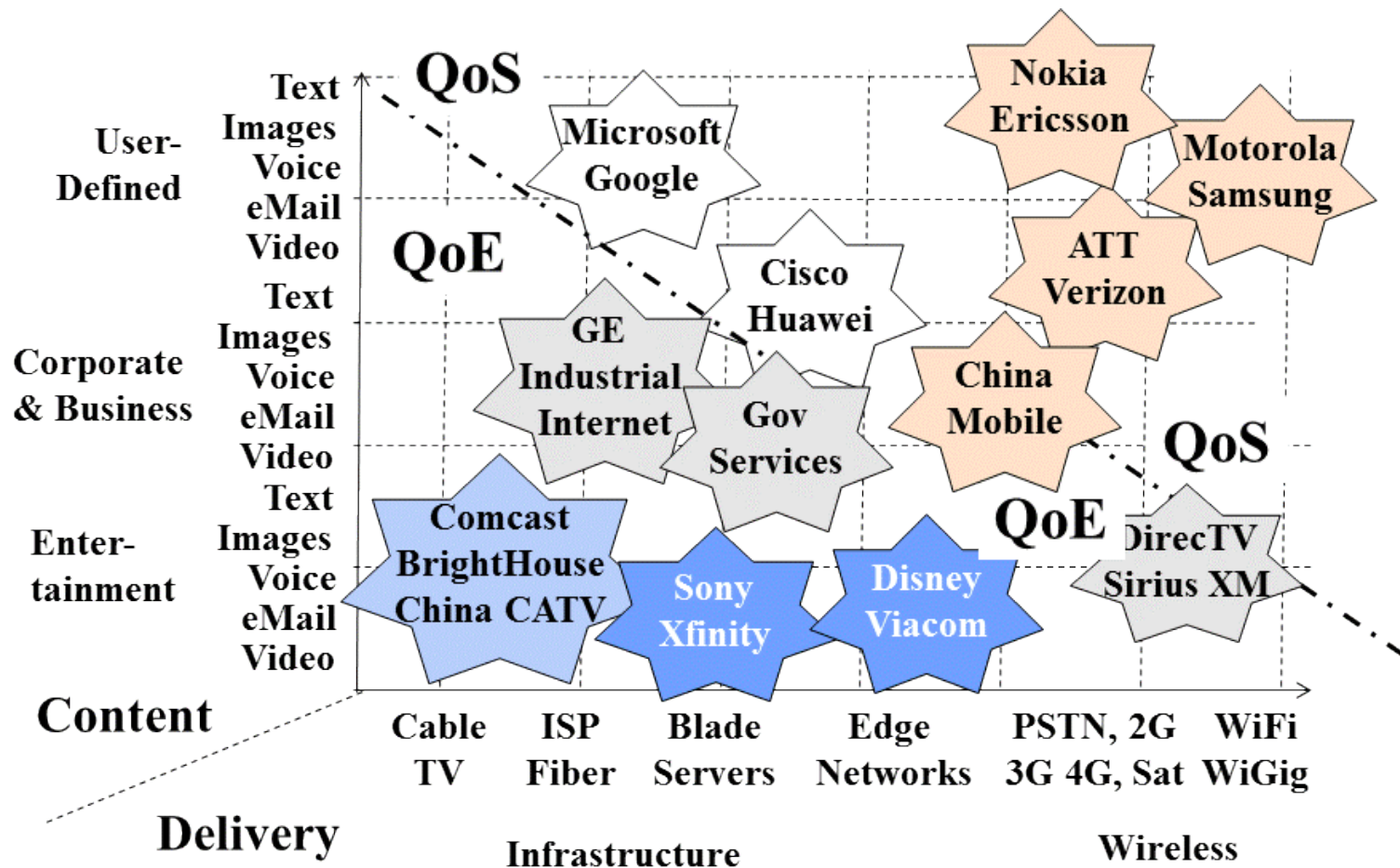
- Market Evolution
 - Bag Phone: Mobility, \$\$\$\$\$ and inconvenience
 - StarTac: Mobility, \$\$\$\$, convenience
 - GSM, 3G: QoS (dial tone, data rate), mobility, \$\$\$
 - Dynamic Interference Management
 - WiFi: QoS (data rate), \$\$ down, 0\$/month
 - Interference acceptance \Rightarrow radar etiquette
 - iPhone: 2G+WiFi = QoE; \$\$\$ down \$\$ /month
 - ***Appropriate Content, on Time at Low Cost***
 - ***Joint Staff QQT (Quality, Quantity, Timeliness)***



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QoE vs QoS



Summary and Conclusion

- Market acceleration demands spectrum sharing
 - WiFi-like: QoS (data rate), \$\$ down, 0\$/month
 - Interference agility \Rightarrow radar, primary user etiquettes
 - iPhone: 2G+WiFi = QoE;
- Spectrum Sharing Reduces Cost (and Price)
 - Chipsets and infrastructure are positioned
 - 5G QoE via Interference-managed Shared Spectrum
 - 6G Multi-function RF – leap-ahead opportunities
 - ***Free spectrum isn't free, but could be affordable***